Flexible Radiation Codes for Numerical Weather Prediction Across Space and Time Scales

Robert Pincus
University of Colorado
325 Broadway, R/PSD1
Boulder, CO 80305
phone: (303) 497-6310 fax: (303) 497-6449 email: Robert.Pincus@colorado.edu

Award Number: N00014-11-1-0441
http://www.esrl.noaa.gov/psd/people/robert.pincus

LONG-TERM GOALS

We seek to develop radiation parameterizations for Navy models that are computationally efficient and work seamlessly across models at all time and space scales, especially from regional models to global models.

OBJECTIVES

We are adapting radiation codes developed for climate models for use in the Navy's global weather forecast model (NOGAPS/NAVGEM) and limited area model (COAMPS). Our long-term goal is to develop codes that are scale-aware, computationally efficient across a range of computer architectures, and operate continuously rather than at infrequent "radiation time steps".

APPROACH

We have developed radiation codes known as "PSrad" which are modeled on the RRTMG parametization (Mlawer et al. 1997; Iacono et al. 2008). We make use of the RRTMG description of gas optics, which is among the most accurate parameterizations available (Oreopoulos et al. 2012) and initially make many of the same algorithmic decisions, including the choice to neglect longwave scattering. Our codes are intended as a drop-in replacement for RRTMG (which has already been implemented in Navy forecast models by Ming Liu) but we have implemented it almost entirely from scratch. The most important technical difference lies in the organization: we have made the code substantially more modular, and each of our subroutines is designed to operate on many columns at a time, a choice that increases computational efficiency on a wide range of platforms. Operational centers such as the European Centre for Medium-Range Weather Forecasts have often modified RRTMG in this way (Morcrette et al. 2008).

Sub-grid scale variability is treated using "sub-columns" (Räisänen et al. 2004; Pincus et al. 2006): discrete random samples, each treated as internally homogeneous, that are consistent with the distributions of possible cloud states within each column, including fractional cloudiness in each layer and assumptions about the vertical correlations between layers (so-called "cloud overlap"). This treatment is a generalization of the Monte Carlo Independent Pixel Approximation (Pincus et al. 2003).

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The main functional innovation in PSrad is support for a range of choices for spectral sampling, including broadband integration (most likely applied at relatively infrequent "radiation time steps") amd a finite number of pre-determined "leagues" of *g*-point teams constructed to limit the error in surface fluxes, as described in Pincus and Stevens (2013).

WORK COMPLETED

The initial version of PSrad is now complete, thorougly tested and debugged, is functioning as the radiation scheme in the climate model ECHAM 6.2 developed at the Max Planck Institute for Meteorology. Implementation in ECHAM exposed the code to a wider range of critical eyes and identified some bugs and other inconsistentices. The code has been somewhat refined for computational performance and portability. We built a "fast math library" module, for example, that encapsulates some of the frequently-used calls to functions like the exponential; compiler directives allow for highly-optimized vendor-supplied vector versions to be used where available. We continue to optimize some of our numerics, especially those related to the two-stream calculations required for shortwave fluxes.

Despite these optimiziations, PSrad is 2-3 times slower (depending on the platform) than the RRTMG code from which it descends *when doing broadband integration* (i.e. all spectral intervals). The majority of this slowdown is due to the calculation of gas absorption coefficients from temperatures, pressures, and gas concentrations. RRTMG's calculations are efficient because the same spectral quadrature point is used by all columns and each point is done in order, where PSrad makes neither assumption. We continue to explore ways to reduce this disparity in computational cost.

About eighteen months ago ECMWF approached us about a collaboration to assess the utility of the spectral sampling approach in reducing certain temperature errors due to complicated terrain. This collaboration is slowly ongoing.

RESULTS

The goal of PSrad was not to reproduce the results of RRTMG but rather to explore the impact of more frequent but noisy estimates of radiation on the accuracy of model forecasts. We took two approaches. The first treats the parameterization problem abstractly and assess the degree to which various radiative transfer approximations, including different temporal frequencies of broadband calculations and various sets of g-point teams, affect the evolution of the model as compared to a reference forecasts that computes the complete radiation field at every time step. We did this using a 29-member ensemble of "perfect-model" forecasts with ECHAM. Figure 1 (from Pincus and Stevens, 2013) shows results with respect to the global distribution of 2 m air temperature at T63 resolution, averaged over the first ten days. Root-mean-square differences between any set of forecasts are finite because all approximations use discrete samples to represent cloudiness and so diverge over time; this limit is shown in the pink line. RMS errors for the various approximations are plotted as a rough function of computation time. Our interpretation of this figure is that the divergence of an ensemble from the reference ensemble is primarily controlled by the amount of computational effort spent, regardless as to whether this is spent on broadband calculations of variable frequency (purple dots) or very frequent calculations with g-point teams of various sizes (green dots).

We are also assessing the impact of the sampling approximations on temperature errors in real forecasts with ECMWF. Here error is measured with respect to point SYNOP measurements as opposed to gridded analyses. ECMWF has explored single summer and winter time months and find smaller errors at some stations, worse errors at others, and no statiically significant change at most stations, indicating that errors in most places are not primarily driven by radiation errors. We are working with the Centre to design experiments to isolate the impact of the radiation approximation in a statisically robust way. We are particularly interested in the behavior of the error across spatial scales, since most centers including FNOC can not afford the high spatial resolution (T1279 – T1999) used at ECMWF.

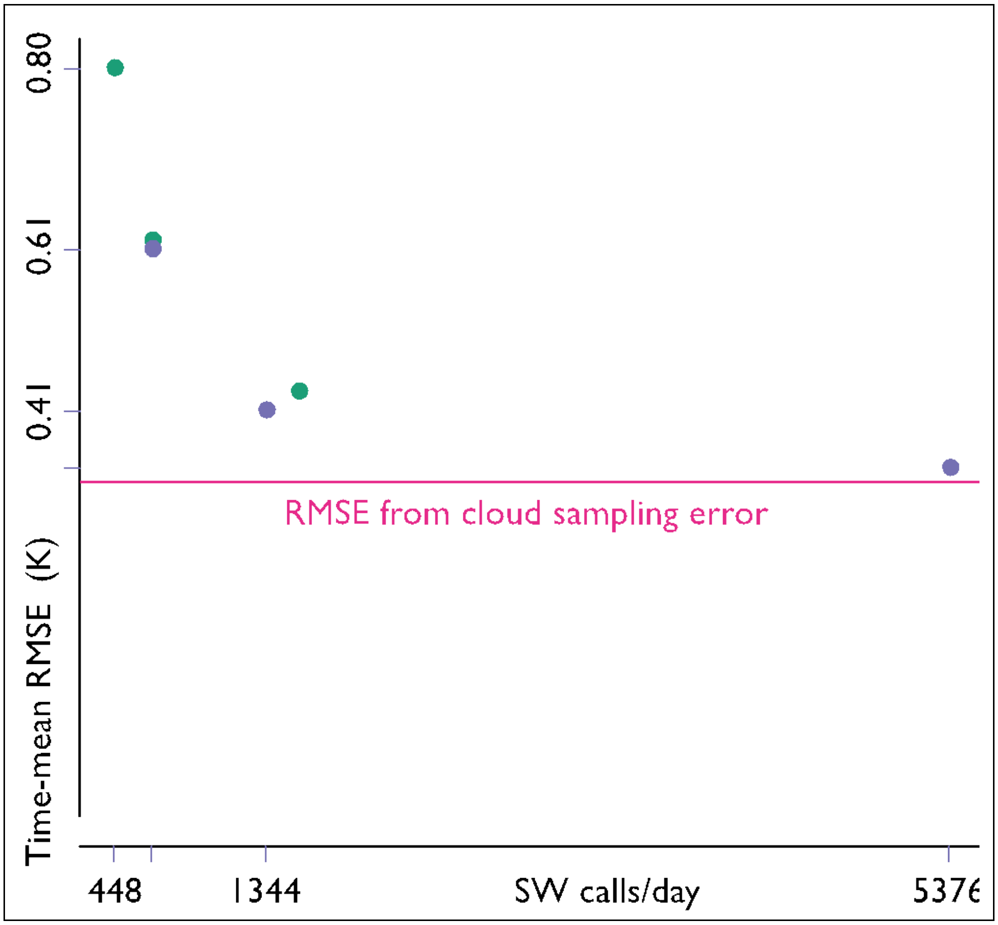

Figure 1: Time-mean error versus a rough measure of computational cost for two methods of coupling radiation and dynamics in a global model. Broadband computations applied sparsely in time are shown in purple and the "teams" of spectral intervals are in green. Error is measured as the mean over 10 days of the global RMS difference in 2 m air temperature relative to a reference forecast, and computational cost as the daily number of calls to the shortwave solver (which dominates the overall cost). The pink line shows the minimum achievable error (i.e., the error introduced by another realization of cloud states sampled in the Monte Carlo independent pixel approximation). Approximation errors for the two sampling strategies are commensurate for a given computational cost.

IMPACT/APPLICATIONS

As mentioned above, the very general approach to spectral integration taken by PSrad means that the code is about twice as slow on some architectures as the RRTMG code from which it is dervied when computing broadband fluxes. Because RRTMG is already implemented in NAVGEM, the desirability of implementing PSrad depends in part on how important it seems to use the capability to replace infrequent broadband calculations with more frequent spectral samples. Initial perfect model results with ECHAM do not suggest a compelling practical reason. This may change when model error is accounted for (i.e. when making real forecasts) and we are exploring this possibilty though our collaboration with ECMWF. But in the short term there seems to be no compelling reason to expend the effort to replace RRTMG with PSrad in NAVGEM. Instead we propose to focus efforts on the regional model COAMPS, where smaller grid sizes and shorter time steps will allow for greater flexibity with respect to radiation choices. (Access to COAMPS code is also more open than has historically been the case with NAVGEM, and this will also facilitate collaboration.)

RELATED PROJECTS

The lessons learned during the development of PSrad were followed closely by other developers including those responsible for RRTMG. To implement bring these ideas back to RRTMG AER, University of Colorado, and computational scientists from NCAR developed a proposal to National Oceanographic Parternship Program (NOPP) to develop high-performance versions of RRTMG that incorporate the functionality of PSrad. These codes will be structured to work efficiently on all platforms including emerging heterogenous architectures such as Graphic Processing Units and Multiple Independent Cores. We have been told that this propsal will be funded but have not received the award yet. We expect the next revision of RRTMG to replace PSrad.

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